Journal of Athletic Training 2005;40(4):305–309
© by the National Athletic Trainers' Association, Inc
www.journalofathletictraining.org

original research

A New Force-Plate Technology Measure of Dynamic Postural Stability: The Dynamic Postural Stability Index

Erik A. Wikstrom*; Mark D. Tillman*; Andrew N. Smith†; Paul A. Borsa*

*University of Florida, Gainesville, FL; †United States Naval Academy, Annapolis, MD

Erik A. Wikstrom, MS, ATC, and Mark D. Tillman, PhD, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Andrew N. Smith, PhD, contributed to conception and design, analysis and interpretation of the data, and critical revision and final approval of the article. Paul A. Borsa, PhD, ATC, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

Address correspondence to Erik A. Wikstrom, MS, ATC, Department of Applied Physiology and Kinesiology, University of Florida, PO Box 118205, Gainesville, FL 32611-8205. Address e-mail to ewikstrom@hhp.ufl.edu.

Context: New measures of dynamic postural stability are needed to address weaknesses of previous measures.

Objective: To assess the feasibility, reliability, and precision of a new measure of dynamic postural stability.

Design: A single within-subjects design was used to determine optimal sampling interval as well as intersession reliability.

Setting: Biomechanics laboratory.

Patients or Other Participants: Eighteen subjects (7 men [age = 22 ± 3 years, height = 175 ± 5 cm, mass = 75 ± 16 kg] and 11 women [age = 23 ± 2 years, height = 163 ± 6 cm, mass = 68 ± 13 kg]) without lower extremity impairment.

Intervention(s): A jump protocol that required subjects to perform a 2-legged jump to a height equivalent to 50% of their maximum vertical leap and land on a single leg.

Main Outcome Measure(s): The Dynamic Postural Stability Index (DPSI) and the directional components (medial-lateral, anterior-posterior, and vertical) after a jump landing.

Results: We observed a significant sampling-interval main effect ($F_{2,51} = 26.88$, $P < .01$) for the DPSI; the 10-second trial duration produced significantly smaller means than the 5- and 3-second trial durations, whereas the 5-second trial result was also significantly smaller than that of the 3-second trial. The DPSI was highly reliable between test sessions (intraclass correlation coefficient = .96) and very precise (SEM = .03).

Conclusions: These results suggest that the DPSI can be used in conjunction with a functional single-leg hop stabilization test and is a reliable and precise measure of dynamic postural stability. We believe the shortest sampling interval (3 seconds) is the best choice for studying and mimicking athletic performance as closely as possible.

Key Words: jump landings, ground reaction forces, sampling intervals, time to stabilization

Dynamic postural stability can be defined as, and measured by an assessment of, an individual's ability to maintain balance while transitioning from a dynamic to a static state.[1] Both static postural stability and dynamic postural stability are the result of complex coordination of central processing from visual, vestibular, and somatosensory pathways, as well as the resultant efferent response.[2] However, postural stability, which is frequently assessed during periods of quiet stance, may fail to elicit postural stability deficiencies because of the relative ease of the testing procedure.[3] Therefore, dynamic and clinical measures were developed to overcome the shortcomings of static measures. Reimann et al[3] subjectively assessed multiple single-leg hop tests, but this is not an objective measure. Similarly, the Biodex Stability System (Biodex Medical Systems, Shirley, NY) objectively measures the degree and time of tilt about unstable axes.[4] The reliability of these measurements was shown to correlate well with data from static force plates[5]; however, maintaining balance on an unstable platform does not represent athletic activity. Yet single-leg hop stabilization tests[6–11] are challenging and most closely mimic athletic performance in the measures mentioned above.

Time to stabilization (TTS) is an example of an objective postural control measure that is used in conjunction with a functional jump protocol. The TTS is defined as the time required to minimize resultant ground reaction forces (GRFs) of a jump landing to within a range of the baseline (static) GRF. As an aspect of motor control for the lower extremity, TTS depends on proprioceptive feedback and preprogrammed muscle patterns, as well as reflexive and voluntary muscle responses.[12] Time to stabilization has been used to evaluate the effects of fatigue[6]; group differences among subjects with healthy, deficient, and reconstructed anterior cruciate ligaments[7]; patients with functional ankle instability[8–10,13]; and motor control from drop jumps.[13]

However, TTS has several inherent flaws, such as being measured from the forces created in 3 directions for each landing (vertical, medial-lateral [M-L], and anterior-posterior [A-P]), which gives researchers and clinicians 3 separate measures of dynamic postural stability. Some would argue that multiple-force directions are beneficial, as they may indicate directional control deficits, but TTS does not provide a common thread among the 3 force directions. This factor may prevent researchers and clinicians from observing global changes in dynamic postural stability of the lower extremity. Determining differences in TTS scores between healthy and injured populations is another potential problem, as the baseline measures between groups may allow for unequal group comparisons.[11] Additionally, having to perform data reduction and analysis on 3 separate measurement directions to determine if significant side-to-side or between-group differences exist is tedious and a limitation of the 3-direction TTS measure.

Researchers have calculated various measures of static and dynamic postural stability with various trial durations ranging from 5 to 60 seconds during static stance[1,2,14–16] and from 3 to 20 seconds during jump landings.[6,7,9,10] For example, some TTS trials use a 20-second duration, which is not as representative of athletic activity as are shorter trial durations.[9,10] Therefore, a new comprehensive measure of dynamic postural stability is needed to improve on the shortcomings of previous measures while maintaining their respective beneficial qualities. Thus, our purpose was to assess the feasibility, reliability, and precision of a new measure of dynamic postural stability: the Dynamic Postural Stability Index (DPSI). This measure is based on previous assessments of single-leg stance and single-leg hop stabilization tests with the underlying premise that dynamic postural stability depends on lower extremity kinematics at landing as well as on muscular activation patterns and eccentric control.[13] Specifically, feasibility will be established by (1) determining which sampling interval is optimal for data collection, (2) determining the reliability and precision of the DPSI in healthy subjects, and (3) comparing the reliability and precision of the DPSI with that of TTS.

METHODS

Subjects

Eighteen recreationally active subjects (7 men [age = 22 ± 3 years, height = 175 ± 5 cm, mass = 75 ± 16 kg] and 11 women [age = 23 ± 2 years, height = 163 ± 6 cm, mass = 68 ± 13 kg]) participated in this investigation. During the first test session, subjects read and signed the informed consent and completed a medical history questionnaire to determine eligibility. All subjects were free from any chronic lower extremity injuries (eg, ankle instability, anterior cruciate ligament deficiency, tendinitis). Additionally, all subjects were free from lower extremity and head injuries for the previous 3 months, and none had any equilibrium disorders. The study was approved by the university's institutional review board.

Procedures

Subjects reported to a research laboratory for all test sessions and were randomly assigned to perform the jump-landing task on either the dominant limb (2 men, 5 women) or nondominant limb (5 men, 5 women) for a unilateral assessment. Limb dominance was defined as the limb that the subject would use to kick a soccer ball, and limbs were randomly assigned to improve the generalization of the results. Each subject was tested during 3 test sessions, all within a 5-day period, with an intersession interval of at least 24 hours and no more than 48 hours. Subjects' maximum vertical jump was tested as described by Wikstrom et al.[6,10] Baseline measures of static stance were then recorded at 200 Hz as a single-leg stance on a force plate during a 5-second window taken on the first day of data collection.[9] Subjects completed 3 successful jump-protocol trials.

The jump protocol was performed as first described by Ross and Guskiewicz.[9] Subjects started in a standing position 70 cm from the center of the force plate. Each subject was required to jump with both legs and touch an overhead marker, which was placed at a position equivalent to 50% of the subject's maximum vertical leap, with a single arm of his or her choosing before landing on the force plate. Each subject was to land on the test leg, stabilize as quickly as possible, and balance for 10 seconds with hands on the hips, looking straight ahead. All subjects were instructed to jump with their heads up and hands in a position to touch the designated marker and place their hands on their hips as soon as they felt stable. Subjects were allowed as many practice trials as needed to feel comfortable with the jump protocol and a 2-minute rest period before completing the testing protocol to prevent fatigue.

If a subject lost balance and touched the floor with the contralateral limb, the trial was discarded and repeated. Similarly, if a short additional hop occurred on landing or if excessive swaying of the contralateral limb, arms, or trunk occurred, the trial was discarded and repeated. Excessive swaying was operationally defined as enough sway that the subject all but stepped off the force plate. Supporting the decision to remove trials with excessive sway were subjects' statements indicating that if they were not participating in a scientific investigation, they would not have attempted to maintain the single-leg stance. Subjects then returned 2 additional times and completed identical jump protocols. However, we collected only the static stance (body weight) data during the first session and used these for all subsequent calculations. A Bertec triaxial force plate (Bertec Corp, Columbus, OH) was used to collect the baseline and jump-landing GRF data (reported in Newtons at 200 Hz). The force-plate data underwent an analog-to-digital conversion and were stored on a personal computer by using the DATAPAC 2000 analog data acquisition, processing, and analysis system (Run Technologies, Laguna Hills, CA). A Bertec amplifier (model AM6300) low-pass filtered the GRF data with a frequency of 1000 Hz and a gain setting of 1.

Data Reduction

Dynamic Postural Stability Index. All data were reduced by a QuickBasic subroutine (version 4.5; Microsoft Corp, Redmond, WA), which calculated stability indices (SIs) in the 3 principal directions (M-L: MLSI, A-P: APSI, vertical: VSI) and the DPSI. These indices are mean square deviations assessing fluctuations around a 0 point, rather than SDs assessing fluctuations around a group mean. The MLSI and APSI assess the fluctuations from 0 along the frontal and sagittal axes of the force plate, respectively. The VSI assesses the fluctuation from the subject's body weight to standardize the vertical GRF along the vertical axis of the force plate. This is done to normalize the vertical scores among individuals with different body weights (mass). The DPSI is a composite of the MLSI, APSI, and VSI and is sensitive to changes in all 3 directions.

$$\mathrm{MLSI} = \sqrt{}[\Sigma(0 - x)^2/\text{number of data points}]$$

$$\mathrm{APSI} = \sqrt{}[\Sigma(0 - y)^2/\text{number of data points}]$$

$$\mathrm{VSI} = \sqrt{}[\Sigma(\text{body weight} - z)^2/\text{number of data points}]$$

$$\mathrm{DPSI} = \sqrt{}[\Sigma(0 - x)^2 + \Sigma(0 - y)^2 + \Sigma(\text{body weight} - z)^2/\text{number of data points}]$$

Table 1. Dynamic Postural Stability Index and its Directional Components (Mean ± SD)

	3 Seconds	5 Seconds	10 Seconds
Dynamic Postural Stability Index*	.77 ± .15	.62 ± .12	.48 ± .08
Directional Components			
Medial-lateral stability index	.22 ± .05	.22 ± .06	.20 ± .06
Anterior-posterior stability index*	.38 ± .05	.31 ± .04	.25 ± .02
Vertical stability index*	.62 ± .15	.48 ± .12	.34 ± .09

*Indicates significant differences between 3 and 5 seconds, between 3 and 10 seconds, and between 5 and 10 seconds.

Table 2. Correlation Matrix Establishing the Linear Relationship Among Dynamic Postural Stability Index Values

	3 Seconds	5 Seconds	10 Seconds
3 Seconds	—	.96*	.92*
5 Seconds		—	.99*

*Significant correlation ($P < .01$).

The data were initially collected and analyzed at 10 seconds and 200 Hz. Data were then reduced to 5- and 3-second post-landing time frames and run through the QuickBasic program again. We used the average values from the 3 successful trials on the first day for each sampling interval for the analysis of the effect of sampling interval on the dependent variables. The average values from the 3 successful trials of all 3 days for the 3-second sampling interval were used for reliability analysis of each of the dependent variables.

Time to Stabilization. All data were analyzed by using the method first described by Colby et al.[7] We determined the M-L and A-P TTS scores by sequential estimation. This technique incorporates an algorithm to calculate a cumulative average of the data points in a series by successively adding in 1 point at a time.[7] We compared this cumulative average with the overall series mean, and the individual series was considered stable when the sequential average remained within 0.25 SDs of the overall series mean. The series consists of all data points within the first 3 seconds after touch down. Vertical TTS was established as the time when the vertical-force component reached and stayed within 5% of the subject's body weight after landing. A subject's body weight was determined before data collection and calculated as the average of the vertical GRF during a 5-second static stance. The average values from the 3 successful trials of each day were then used for reliability analysis.

Statistical Analysis. Separate 1-way analyses of variance were performed to determine if there were significant differences in the DPSI and its directional components among the levels of sampling interval (10, 5, and 3 seconds) from the data collected on the first day. The Scheffé post hoc test was computed when appropriate and a Pearson product moment correlation coefficient was calculated to determine if a relationship existed between means. Test-retest reliability for the DPSI and TTS measures was calculated using an intraclass correlation coefficient (ICC [3,1]) formula.[17] In addition, SEM values were calculated for the same variables. All reliability coefficients were interpreted as follows: below 0.69 = poor, 0.70 to 0.79 = fair, 0.80 to 0.89 = good, and 0.90 to 1.00 = excellent.[18] An alpha level of .05 was used for all statistical tests.

RESULTS

Manipulating the sampling interval caused significant differences in the DPSI ($F_{2,51} = 26.88$, $P < .01$) (Table 1). Scheffé post hoc tests indicated that the 3-second sampling interval produced significantly larger DPSI scores than did the 5- and 10-second intervals, and the 5-second interval produced significantly larger DPSI scores than did the 10-second interval. Similarly, differences in sampling interval caused significant differences in APSI ($F_{2,51} = 56.64$, $P < .01$) and VSI ($F_{2,51} = 21.60$, $P < .01$). Scheffé post hoc tests revealed that as with the DPSI, the 3-second sampling interval produced significantly larger APSI and VSI scores than did the 5- and 10-second times, and the 5-second time produced significantly larger APSI and VSI scores than did the 10-second time (see Table 1). However, changes in sampling interval did not cause significant differences in MLSI ($F_{2,51} = .68$, $P = .51$).

Pearson correlation values demonstrated a linear relationship among the DPSI values calculated for each sampling interval, with an r value ranging from .917 to .990 (Table 2). The ICC values revealed that the DPSI possessed higher ICC values and more precise SEM values than the TTS (Table 3).

DISCUSSION

Sampling Interval

Our objective was to determine the feasibility of a new technique to measure dynamic stability based on the previous as-

Table 3. Time-to-Stabilization Scores, Dynamic Postural Stability Index, and Directional Components (Reliability and SEM at the 3-Second Sampling Interval)*

	Time to Stabilization (Milliseconds)			Stability Index			
	Medial-Lateral	Anterior-Posterior	Vertical	Dynamic Postural Stability Index	Medial-Lateral	Anterior-Posterior	Vertical
Mean	1133.00	1696.00	1650.00	.77	.22	.38	.62
ICC (3, 1)	.66	.80	.78	.96	.38	.90	.97
95% Confidence interval of ICC	.41–.84	.62–.91	.59–.90	.91–.98	.08–.66	.80–.96	.94–.99
ICC Rating	Poor	Good	Fair	Excellent	Poor	Excellent	Excellent
SEM†	210.00	55.00	290.00	.03	.06	.02	.03
% of mean	18.50	3.20	17.60	3.70	26.10	5.00	4.60

*ICC indicates intraclass correlation coefficient.
†SEM = s ($\sqrt{1-r}$) where s is the SD and r is the ICC.

sessments of single-leg stances and single-leg hop stabilization tests. The first step in assessing this measure was to determine the optimal sampling interval from the force plate. Altering the sampling interval significantly affected the DPSI and all the directional indices except MLSI. The high variability associated with stability in the M-L direction during a single-leg stance may explain the lack of an effect in the frontal plane. These results are similar to those of Schmitz and Arnold,[19] who showed the reliability of the MLSI on a Biodex Stability System was poor (.43). This comparison can be made because the reliability of the data points from a Biodex Stability System was correlated with that from static force plates.[5] This increased variability may have been why altering the sampling interval did not affect the MLSI. However, it is also possible that the MLSI scores were not affected because of the A-P orientation of the landing task. Furthermore, we found a linear relationship such that the mean DPSI scores, which incorporate the directional indices, decreased linearly as the sampling intervals increased from 3 to 10 seconds (see Table 2).

This linear relationship was important in our attempt to find the most functional sampling interval. During landing, the initial GRF reflects shock absorption, followed by a balance phase. The method used to calculate the dependent measures incorporates both landing phases and places more emphasis on a subject's ability to absorb shock than maintain balance because of the association between increased GRF and lower extremity injury.[20–22] The decrease seen in DPSI scores as the sampling interval increases could be caused by several factors. The higher GRF at touch down and the significantly smaller GRF during the single-leg stance should play a small role in the relationship because the longer the trial duration, the less weight the shock-absorption phase will have within the DPSI calculation. However, the impact forces would be present in each sampling interval, and the mean square deviations should not differ significantly among sampling intervals. Therefore, the largest factor in the linear relationship is most likely the sampling interval itself. In each of the directional and DPSI equations, the number of data points (directly related to the sampling interval) serves as the denominator. As the denominator increases, the ratio decreases proportionally. This is shown by the decrease in the means and SDs as the trial duration is increased. The high correlation values indicate that investigators can use any sampling interval within the range used in this investigation (3–10 seconds) because of the linear relationship. However, researchers wishing to study and mimic athletic performance as closely as possible should use the shortest sampling interval (3 seconds), which is the closest to functional activities of sport. Using a more functional sampling interval will allow research to be tailored to clinical situations and provide a better understanding of how the lower extremity functions during activity. These results are also important because they will allow better comparisons among investigations with different sampling intervals.

Precision and Reliability

The SEM of the DPSI was shown to be extremely small (.03), given the mean of the DPSI (.81). According to Denegar and Ball,[17] the SEM is a measure of the DPSI's precision and demonstrates that we are 95% confident that the measured values lie within $\pm$.03 of the true DPSI. In addition, the reliability of the DPSI was shown to be excellent between test sessions (.96).[18] The reliability of .96 is higher than that reported by Schmitz and Arnold,[19] who found the intra- and intertester reliabilities of the Biodex Stability System were .82 and .70 for the overall stability index score. It is important to note that Hinman[5] showed that the reliability of the data points of the Biodex Stability System was comparable with that produced by static force plates. In addition, the reliability of the DPSI and its directional components was higher than that for the TTS scores calculated from the same data points in the current investigation (see Table 3).

Similarly, the reliability of the DPSI is at least equivalent to that described by Colby et al,[7] who reported reliability coefficients for the dominant and nondominant limbs with a hop stabilization test similar to the one used in this investigation. Colby et al[7] calculated the reliability of the TTS measures by using both the GRFs and SDs of the A-P, M-L, and vertical forces. The ICC for GRF ranged from .872 to .971, whereas the ICC for the mean square deviations of those forces ranged from .951 to .988. The authors' results provide evidence that the mean square deviation of the GRF is more reliable than the GRF itself. These results also support the use of the DPSI because it is calculated by taking the mean square deviation or the amount of variance in the GRF from a 0 point rather than the GRF. One possible reason is that the mean square deviation could be a mathematical filtering technique that accounts for momentary accelerations and decelerations of the center of gravity that help maintain equilibrium.

Time-to-Stabilization Comparison

The DPSI is at least as accurate and precise as TTS but provides a comprehensive measurement of dynamic postural stability that is sensitive to change in 3 directions. However, the DPSI does not sacrifice individual directional measurements (MLSI, APSI, VSI) to create a global measure of dynamic postural stability. The directional measures of the DPSI are comparable with the TTS measures (M-L, A-P, vertical). The ability to examine both a global measure and directional measures allows researchers and clinicians not only to note directional control deficits but also to potentially see how those deficits affect a more global measure. The main difference between TTS and the DPSI is the time component. Time to stabilization measures the time it takes for an individual to stabilize, whereas the DPSI is a unitless measure of overall stability. Therefore, both types of evaluations (TTS for time-based directional measures and DPSI for directional and global measures) can be used for separate clinical questions.

Both the TTS and the DPSI are calculated in conjunction with a single-leg jump stabilization maneuver. In previous investigations[6,10] within our laboratory, we have noted that several failed attempts occur with this landing protocol, regardless of the amount of practice allowed. However, allowing sufficient practice minimizes failed attempts during the testing session. Although quick and effective testing is ideal for clinicians and researchers alike, the importance of failed trials has often been overlooked. A comparison of failed and successful trials could reveal valuable information, as could the number of failed trials by subjects within certain groups. Therefore, the number of practice and failed trials should be evaluated in future investigations, as they have implications for dynamic postural stability assessment. In addition, the setup and testing time per subject is reasonable. After the initial setup (force-plate warm-up and calibration), subjects can be safely tested within a 15- to 20-minute window. This time frame allows for instruction, practice, subsequent rest, and the testing protocol while allowing for failed trials.

CLINICAL IMPLICATIONS

The excellent test-retest reliability and precision of the DPSI point to numerous potential applications in future research and clinical settings. Primarily, the excellent reliability and precision indicate that the DPSI could detect and identify changes in dynamic postural stability over time during numerous laboratory and clinical evaluations. The ability to detect changes in dynamic postural stability is extremely valuable when examining the effectiveness of neuromuscular training and fatigue programs. In addition, the DPSI could allow for prospective outcomes-oriented investigations to provide a reliable functional measure of dynamic postural stability for preseason screenings, preinjury versus postinjury comparisons, and an objective return-to-play criterion as the athlete or patient progresses through the rehabilitation process.

CONCLUSIONS

The linear relationship with DPSI for various sampling intervals indicates that researchers should use shorter sampling intervals to more closely mimic athletic activity. If possible, the 3-second sampling interval should be used because it is the most functional time. The DPSI is a more reliable and precise measure of dynamic postural stability than TTS while still incorporating the functional single-leg hop stabilization test and maintaining directional components.

REFERENCES

1. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil.* 1989; 70:510–517.
2. Palmieri RM, Ingersoll CD, Cordova ML, Kinzey SJ, Stone MB, Krause BA. The effect of a simulated knee joint effusion on postural control in healthy subjects. *Arch Phys Med Rehabil.* 2003;84:1076–1079.
3. Reimann BL, Caggiano NA, Lephart SM. Examination of a clinical method of assessing postural control during a functional performance task. *J Sport Rehabil.* 1999;8:171–183.
4. Arnold BL, Schmitz RJ. Examination of balance measures produced by the Biodex Stability System. *J Athl Train.* 1998;33:323–327.
5. Hinman M. Factors affecting reliability of the Biodex Balance System: a summary of four studies. *J Sport Rehabil.* 2000;9:240–252.
6. Wikstrom EA, Powers ME, Tillman MD. Dynamic stabilization time after isokinetic and functional fatigue. *J Athl Train.* 2004;39:247–253.
7. Colby SM, Hintermeister RA, Torry MR, Steadman JR. Lower limb stability with ACL impairment. *J Orthop Sports Phys Ther.* 1999;29:444–451.
8. Brown BN, Ross SE, Mynark R, Guskiewicz KM. Assessing functional ankle instability with joint position sense, time to stabilization, and electromyography. *J Sport Rehabil.* 2004;13:122–134.
9. Ross SE, Guskiewicz KM. Time to stabilization: a method for analyzing dynamic postural stability. *Athl Ther Today.* 2003;8(3):37–39.
10. Wikstrom EA, Tillman MD, Borsa PA. Detection of dynamic stability deficits in subjects with functional ankle instability. *Med Sci Sports Exerc.* 2005;37:169–175.
11. McKinley P, Pedotti A. Motor strategies in landing from a jump: the role of skill in task execution. *Exp Brain Res.* 1992;90:427–440.
12. Johnston RB III, Howard ME, Cawley PW, Losse GM. Effect of lower extremity muscular fatigue on motor control performance. *Med Sci Sports Exerc.* 1998;30:1703–1707.
13. Ross SE, Guskiewicz KM. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clin J Sport Med.* 2004;14:332–338.
14. Goldie PA, Evans OM, Bach TM. Steadiness in one-legged stance: development of a reliable force-platform testing procedure. *Arch Phys Med Rehabil.* 1992;73:348–354.
15. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recordings of single limb stance. *Am J Sports Med.* 1984;12:185–188.
16. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med.* 1988;9:141–144.
17. Denegar CR, Ball DW. Assessing reliability and precision of measurement: an introduction to intraclass correlation and standard error of measurement. *J Sport Rehabil.* 1993;2:35–42.
18. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* Norwalk, CT: Appleton & Lange; 1993:509–516.
19. Schmitz RJ, Arnold BL. Intertester and intratester reliability of the Biodex Stability System. *J Sport Rehabil.* 1998;7:95–101.
20. Hreljac A, Marshall RN, Hume PA. Evaluation of lower extremity overuse injury potential in runners. *Med Sci Sports Exerc.* 2000;32:1635–1641.
21. McNair PJ, Marshall RN. Landing characteristics in subjects with normal and anterior cruciate ligament deficient knee joints. *Arch Phys Med Rehabil.* 1994;75:584–589.
22. Mizrahi J, Susak Z. Analysis of parameters affecting impact force attenuation during landing in human vertical free fall. *Eng Med.* 1982;11:141–147.